Bellcomm
955 L'Enfant Plaza North, S.W.
Washington, D. C. 20024

date: July 22, 1971

to: Distribution

from: F. LaPiana

B71 07035

subject: A Summary of the LRV Navigation System
Case 310

ABSTRACT

This memorandum contains information which was pre-pared for a briefing for Dr. Petrone on July 21, 1971. Although all of this information was not presented, the capability of the LRV navigation system to support the Apollo 15 mission was summarized.

The LRV Navigation system consists of an odometer, directional gyroscope, computer, and a display panel. The odometer is comprised of magnetic wheel-mounted devices which trigger digital pulses as the wheel rotates. The pulses go to the computer where the distance increment is resolved into N-S and E-W components. The accumulated component increments are used by the computer to find the range and bearing back to the LM which is displayed to the astroanuts. The gyroscope provides the LRV heading information to the crew and to the computer. Due to its drift, there is a requirement to realign the gyro periodically.

The operating procedure for gyro realignment is for the crew to read to Houston (MCC-H) the LRV pitch, roll and heading relative to the sun. MCC-H uses this and ephemeris data to compute the true LRV heading azimuth which is then used by the crew to align the gyro.

System performance is a function of gyro drift rate, alignment accuracy, and the specific traverse considered.

Realignment requirements for the specified maximum 600 meters of terminal position location error can be easily met. For the Apollo 15 traverses a single realignment on traverse 1, three realignments on traverse 2, and two realignments on traverse 3 are adequate.

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MEMORANDUM FOR FILE

1. Introduction

The LRV navigation system is basically a mechanized dead-reckoning process. The system was designed to be a light weight, compact, dependable, moderately accurate aid for the astronauts to find the LM on returning from a lunar traverse. Accuracy requirements are equivalent to 600 meters in position location error. Previous analysis (1) has shown that this is adequate.

2. Physical System

Figure 1 shows three views of the Lunar Roving Vehicle. The control console, which contains the navigation display, is located on a pedestal between the two astronauts. As shown in Figure 2, the display contains readouts of range to the LM (XX.X KM), bearing to the LM (XXX. deg), traverse distance (XX.X KM), directional gyro gimbal angle (Heading, in 1° markings), and a velocity meter. The power, system reset, and gyro torquing switches are all pull-before-throw type controls.

Range, Bearing, and Distance Counters are initialized with the system reset control. To measure distance, each wheel has nine equally spaced magnetic devices mounted on it. As the wheels rotate, these devices pass stationary reed switches and trigger pulses which are sent to the computer. A composite pulse occurs at the time when the third fastest wheel puts out its third pulse. The composite pulse is scaled to 0.735 meters in the computer. Requiring pulses from three wheels eliminates the effects of wheel slip in two wheels.

Not requiring a pulse from the fourth wheel is an attempt to avoid the effects of a single device failure.

The 0.735 meter distance per pulse includes nominal wheel deformation and slip correction factors. Each 0.735 meter distance increment is resolved into North-South and East-West components using the sine and cosine of the heading angle. These are extracted from the directional gyro selsyn output by a "Scott-T" network. Accumulator digital registers hold the North-South, East-West position of the LRV with respect to the LM. The cartesian position data is then converted to polar form (Range and Bearing to LM) by a novel technique called the Cordic Algorithm. This uses addition and digital shifting processes to convert cartesian coordinates to polar coordinates without using the Pythagorean theorem or arc-tangent functions. As a result it saves considerable computer complexity.

Range and Bearing to the LM are displayed for the crew on the digital counters. These counters are reset only when the system reset switch is used. The system is designed so that if LRV power or navigation system failure occurs, the counters are not automatically reset. The only capability of the reset switch is to zero the counters, hence no position corrections can be made during a traverse even if landmark and/or MCC-H position update data are available.

Periodically the gyro is realigned to correct for its drift since the last alignment. How often alignment needs to be done is a function of the gyro drift rate and the LM relative location accuracy required. Realignment should not be needed so often that it interferes with the purposes of the sortie.

The DIST (distance traveled) readout is used mainly as an indicator of how much traverse capability (battery power) has been used, and thus is an indication of the remaining travel capability of the LRV.

3. Operating Procedures

To align or realign the directional gyro, the LRV is driven so that the sun is within ±15° of dead aft, shining over the shoulders of the astronauts, The gnomon of the sundial is then rotated into position so that its shadow falls on the ±15° Sun Shadow Device (SSD) scale affixed to the console. The crew reads and passes to the Mission Control Center-Houston (MCC-H) the SSD angle, and the LRV pitch and roll angles. The pitch and roll angles are obtained from a simple pendulum device on the left side of the console (Figure 3).

The MCC-H uses these angles and sun/moon ephemeris data to calculate the directional gyro gimbal (Heading) angle. The calculations are done on a desk-top computer. Nomograms are available to solve the same equations as a back-up. These calculations to correct for the effects of LRV pitch and roll are necessary since the SSD is rigidly mounted to the control console, and hence is not a true sundial. The calculated heading angle is voiced to the LRV crew and set on the heading indicator via the gyro torquing control. The Lunar Roving Vehicle Operations Handbook (3) gives 3.8 minutes as that portion of the pre-sortie checkout and preparation timeline needed for the navigation system initialization and alignment. This includes gyro warmup time, data readout, voice link to the MCC-H, and gyro alignment. The total time required for a gyro realignment is given as 1.8 minute.

4. Performance

As was previously stated, the requirement is to keep the position location error of the navigation system less than 600 meters. The error sources considered significant in the navigation system are gyro alignment error and systematic gyro drift. Analysis of the alignment error expected indicates a 3σ value of 3° (1). The gyro specification of 10°/hr maximum drift rate is also taken as the 3σ value. The position location error is dependent on these two parameters, and also on the specific traverse route and timeline used. As a result of this, the system has to be evaluated for each specific traverse considered. As an example, Figure 4 presents the position error as a function of time for Hadley Apennine traverse 3 as revised, January 28, 1971 (2). These traverses are similar to the latest version and provide a realistic basis for navigation analyses. However, some of the science stops have been changed.

Figure 4 demonstrates the effects of 3σ values of the error sources for a selection of realignment options and abort returns to the LM. The system position accuracy performance is shown to be dependent on gyro realignment location selection. The figure also shows that even with the 3σ values of alignment error and drift, the position error can be kept below 600 meters with 2 realignments on traverse 3.

The system performance on the same traverse has also been evaluated for other than the 3σ values of alignment error and drift rate. Figure 5 presents the terminal traverse position location error as a function of gyro drift rate over a spectrum of alignment errors for 3 different realignment options.

The figure shows how the position location error sensitivity to drift rate greatly decreases as the number of realignments is increased. It also shows how, under the same drift conditions, the sensitivity to alignment errors is low. In contrast, for a single realignment at stop 14, increasing the drift rate produces large position errors and at the same time the sensitivity to alignment errors is reduced. A tabulation of the navigation system's performance capability on the traverses of January 28, 1971 is shown in Figure 6. An examination of the data illustrates the traverse-specific effect and the non-linearity of position error as a function of the number of gyro realignments. The table summarizes the gyro realignment requirements to meet various terminal position accuracies for the Apollo 15 mission based on either a 3° or 10° per hour gyro drift rate.

In an abort-return-to-the-LM, the terminal position location accuracy of the system has been evaluated. Both 3° and 10° per hour drift rates and cases with and without gyro realignment at abort time have been calculated. The data, shown in Figure 7, is based on aborting from the farthest point from the LM along each traverse. Earlier realignments on traverses 2 and 3 at stops 4 and 10 respectively are assumed in conformance with the requirements shown in Figure 6.

The entire navigation process has been tested successfully on traverse simulations performed using the 1G LRV trainer at KSC and the MCC-H. In addition, extensive testing of a similar system by MSFC has been very successful.

5. System Utilization

Present plans call for the LRV navigation system also to be used as an aid in point-to-point movements along the traverse. The charts furnished the astronauts for use on the lunar surface are annotated with the heading to be followed, as best they can, during each leg of the traverse. Also given is the length of each leg. This information is used with the navigation system display for point-to-point movements. Mr. Robert Savely of MSC/MPAD has completed an error analysis of the navigation system and has recommended that there be one gyro realignment on traverse 1, 3 on traverse 2, and 2 on traverse 3 (which agrees with results of an earlier Bellcomm study [2]). This will assure a less than 600 meter terminal position error on each traverse with up to 3σ values of alignment error and drift rate. Past experience, especially the MSFC tests which used the same model gyro, indicate that the 3σ values of 3° misalignment and 10° hour are conservative values.

As an emergency back-up aid for returning to the LM the astronauts will carry a simple sun-compass. Using the range and bearing data from the LRV navigation system or as voiced up from the MCC-H, the sun compass will enable them to go in the desired direction. This back-up can be used for either a riding or walking return as necessary.

Francis La Piana

2014-FL-hat F. LaPiana

REFERENCES

1. Technical Memorandum, "The Navigation System of the Lunar Roving Vehicle," TM-70-2014-8, Bellcomm, Inc., W. G. Heffron and F. LaPiana, December 11, 1970.

2. Memorandum for File, "LRV Navigation System Realignment Requirements for the Apollo 15 traverses as Revised, January 28, 1971," B71-04045, Bellcomm, Inc., F. LaPiana, April 22, 1971.

3. "Lunar Roving Vehicle Operations Handbook," Contract NAS 8-25145, The Boeing Company, LRV Systems Engineering, Huntsville, Alabama, LS006-002-2H, December 4, 1970.

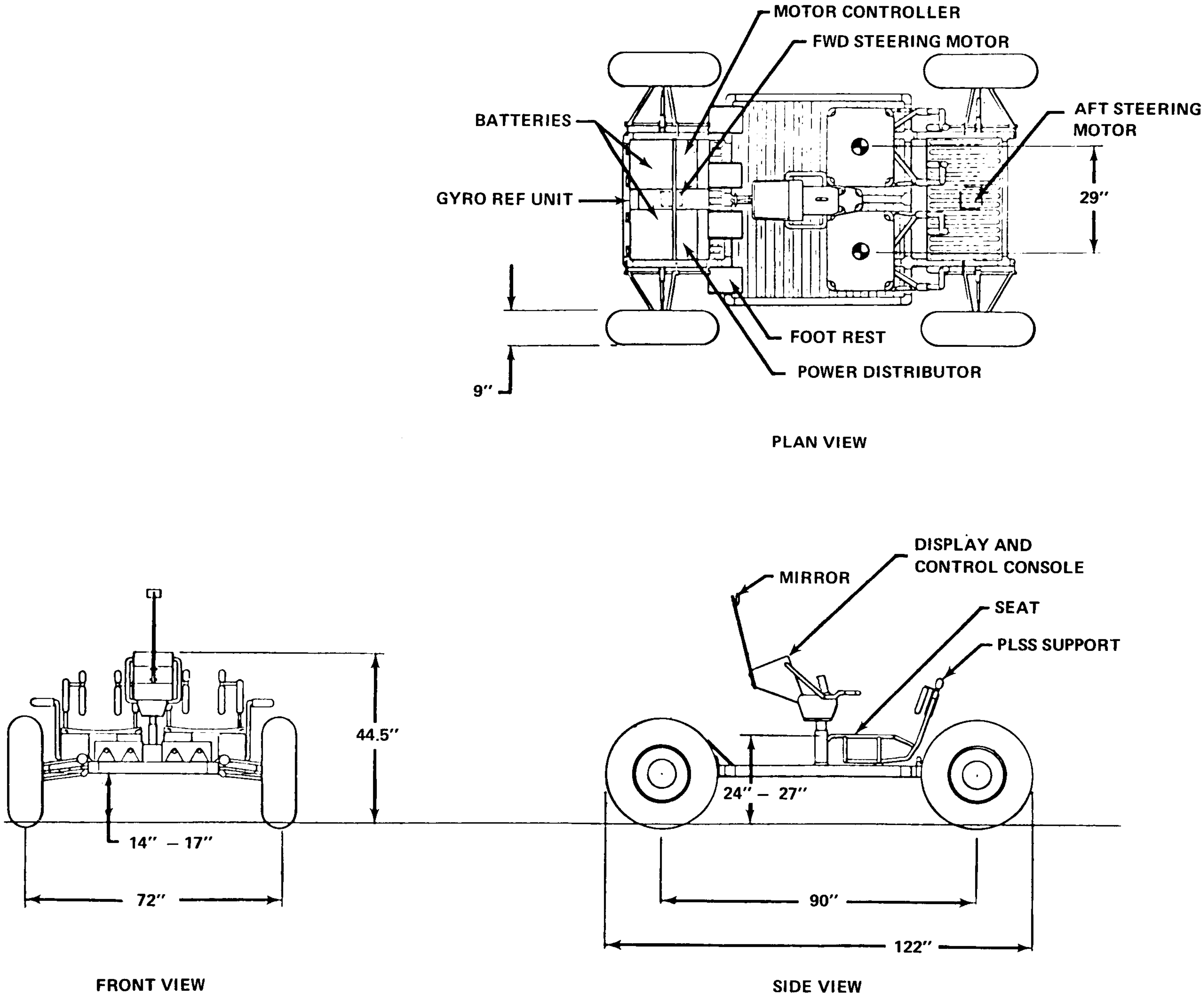

FIGURE 1 - LUNAR ROVING VEHICLE

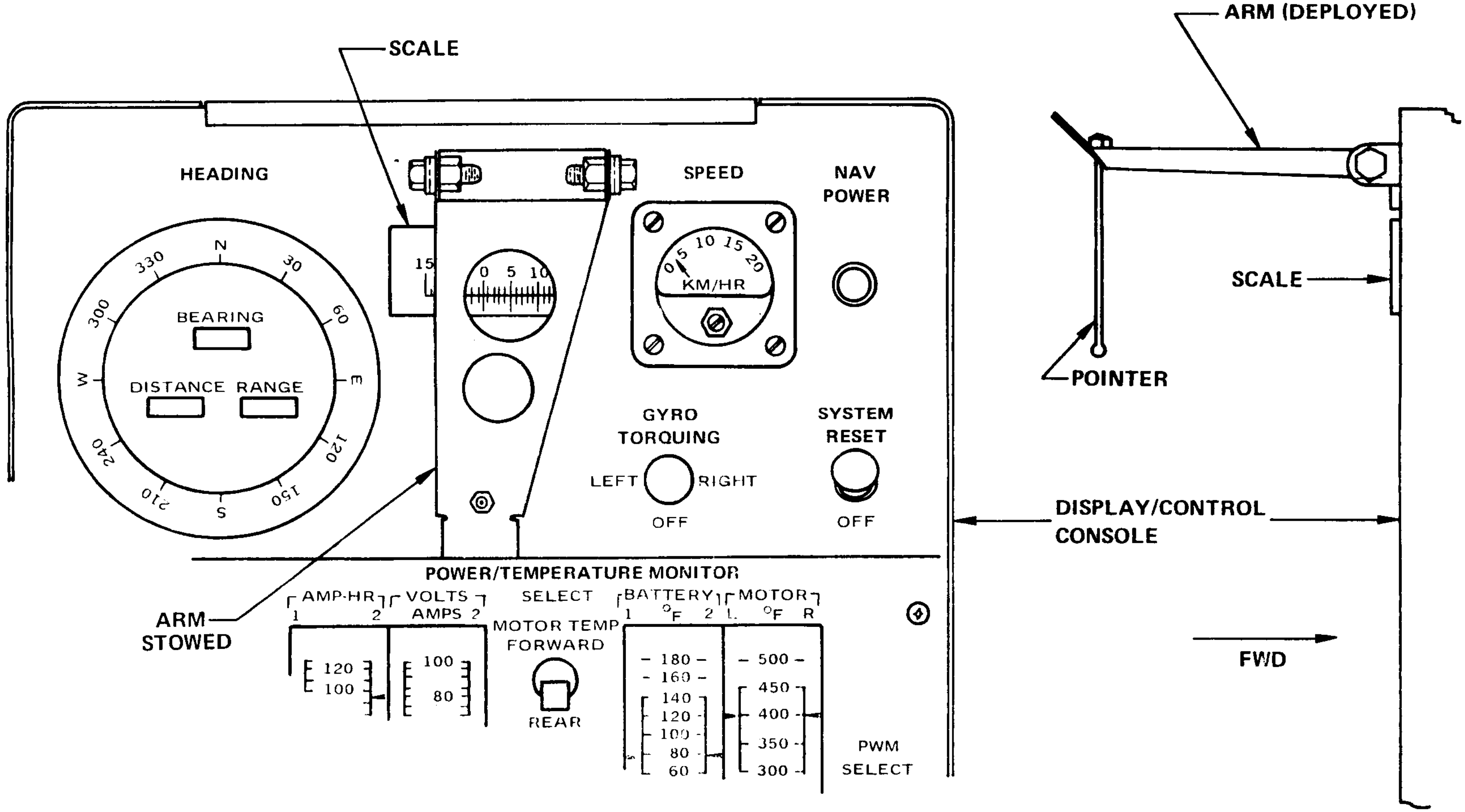

FIGURE 2 - NAVIGATION DISPLAY

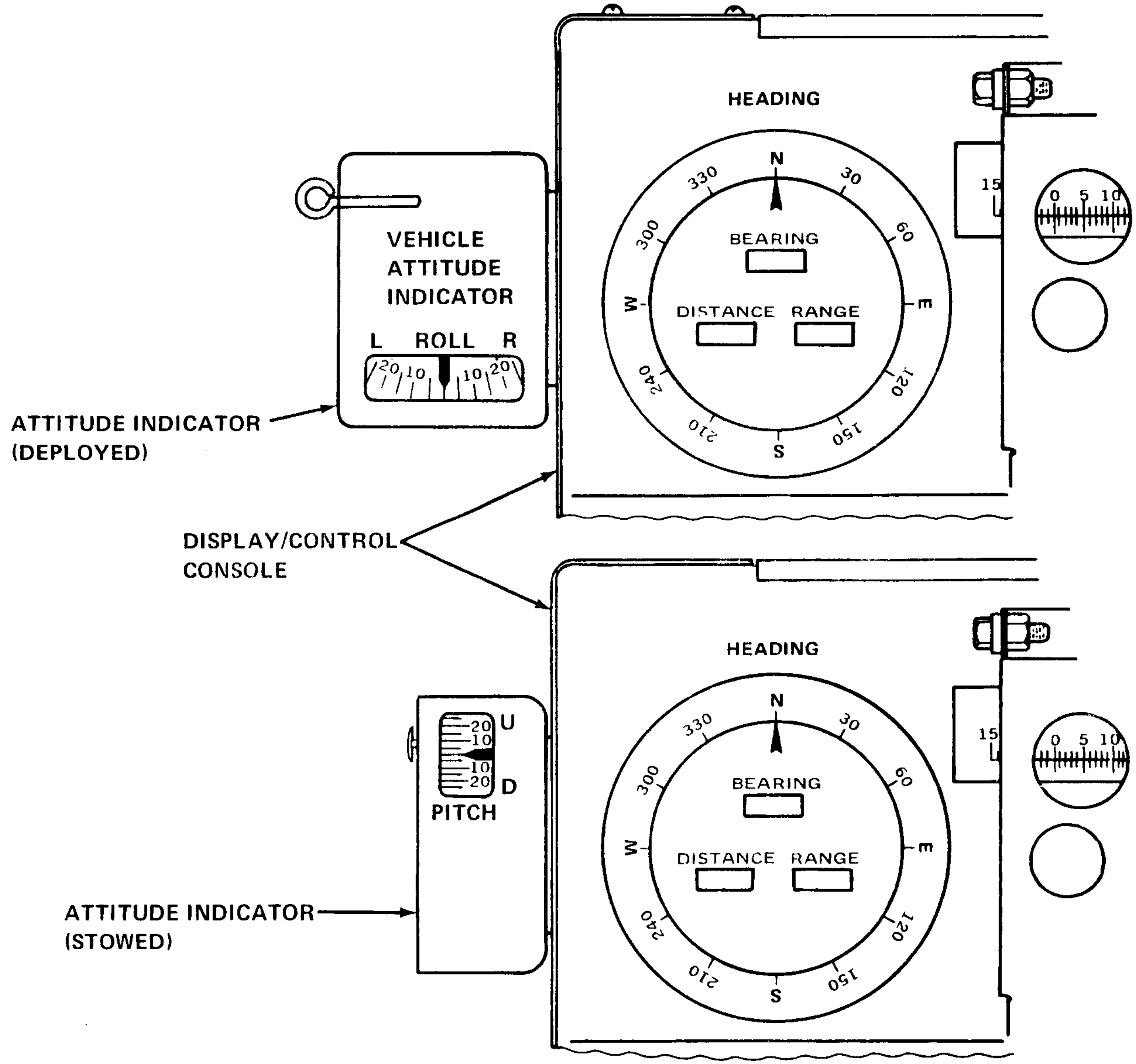

FIGURE 3 - VEHICLE ATTITUDE INDICATOR

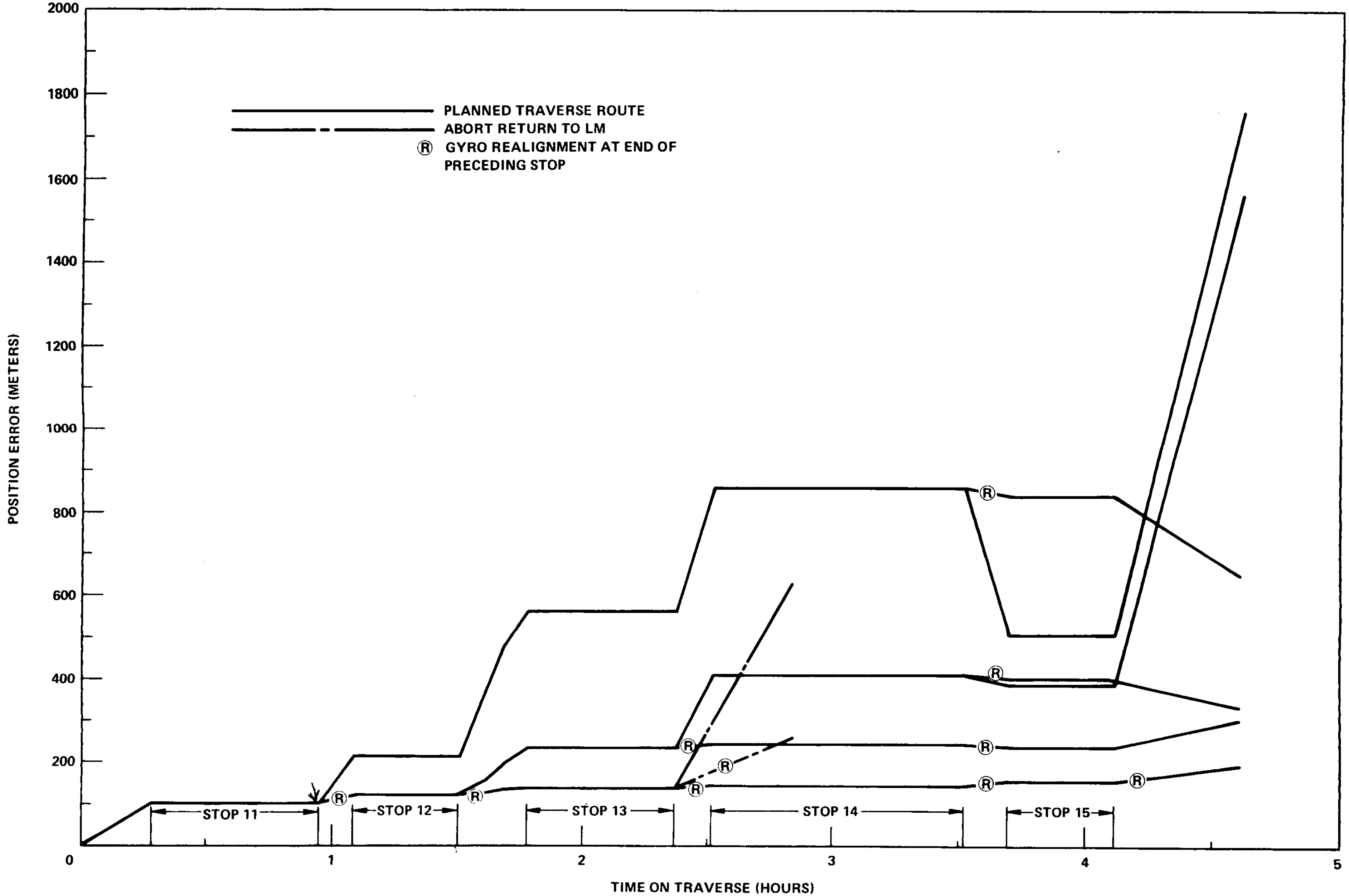

FIGURE 4 - HADLEY APENNINES LRV TRAVERSE 3, REVISION OF 1/28/71. NAVIGATION SYSTEM POSITION ERROR VS TIME FOR 3° REALIGNMENT ERROR AND 10°/HR GYRO DRIFT

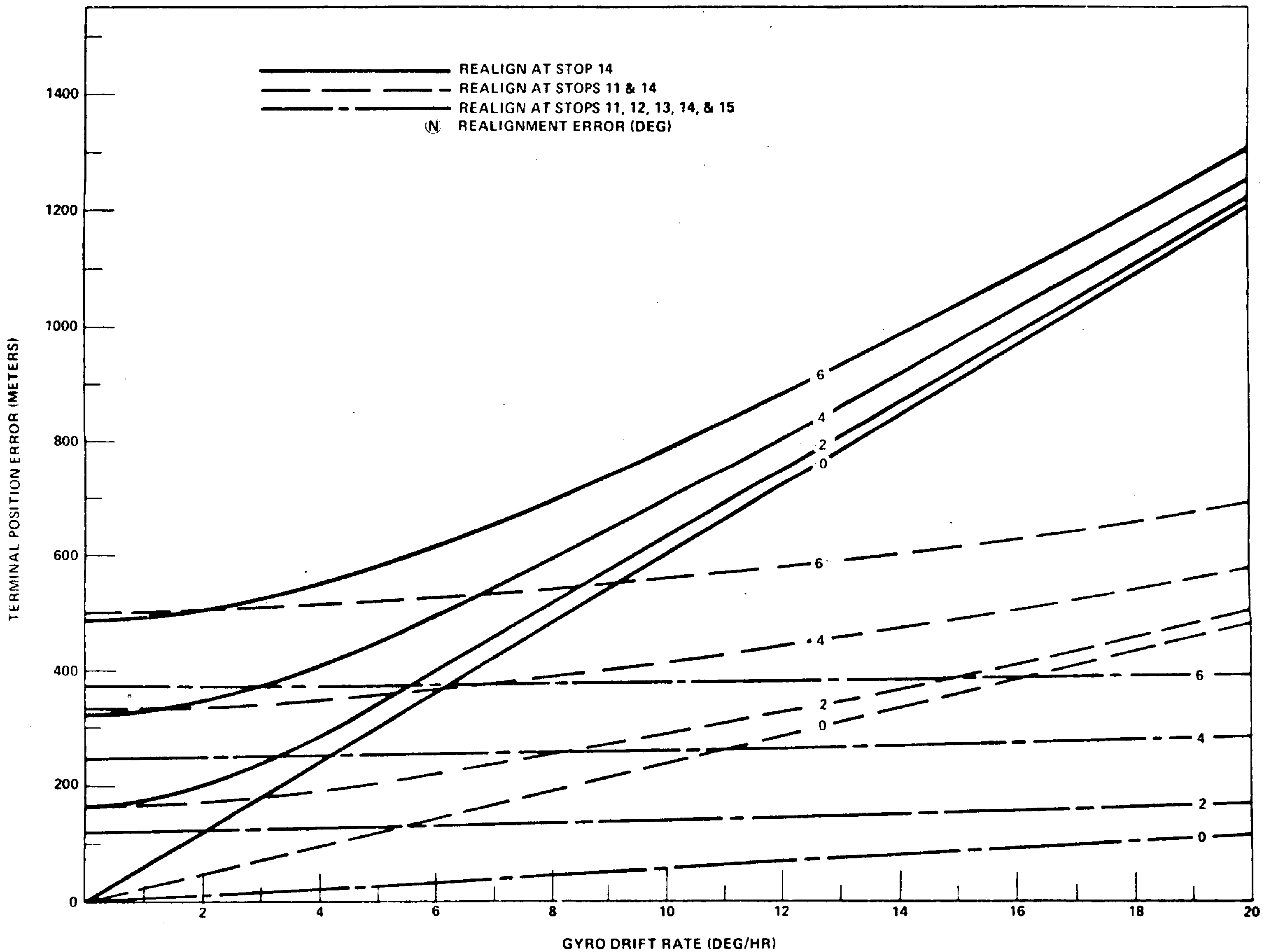

FIGURE 5 - HADLEY APENNINES TRAVERSE 3, REVISION OF 1/28/71. LRV NAVIGATION SYSTEM TERMINAL POSITION ERROR VS GYRO DRIFT RATE FOR SELECTED VALUES OF ALIGNMENT ERROR AND REALIGNMENT POINTS

LRV NAVIGATION
TERMINAL POSITION ERROR (METERS)

		EVA		
		#1	#2	#3
NUMBER OF REALIGNMENTS	0	330/1100	990/3300	530/1770
	1	200/240*	470/900	310/651
	2	210/220	520/650	260/340*
	3	---	310/410*	240/300
	4	---	280/280	---

3°/10° PER HOUR CONSTANT GYRO DRIFT RATE

3° RANDOM MISALIGNMENT ERROR

*Realignments needed
to meet 600 meter limit.

FIGURE 6 - TERMINAL POSITION ERROR

LRV NAVIGATION
ABORT RETURN TERMINAL POSITION ERROR (METERS)

	EVA		
	#1	#2	#3
WITHOUT REALIGNMENT AT ABORT	190/630	330/1850	405/1240
WITH REALIGNMENT AT ABORT	220/230	280/470	230/410

3°/10° PER HOUR CONSTANT GYRO DRIFT RATE

3° RANDOM MISALIGNMENT ERROR

FIGURE 7 - ABORT RETURN TERMINAL POSITION ERROR.

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